Simulating Riverine Dissolved Organic Carbon Export Across The Western Arctic

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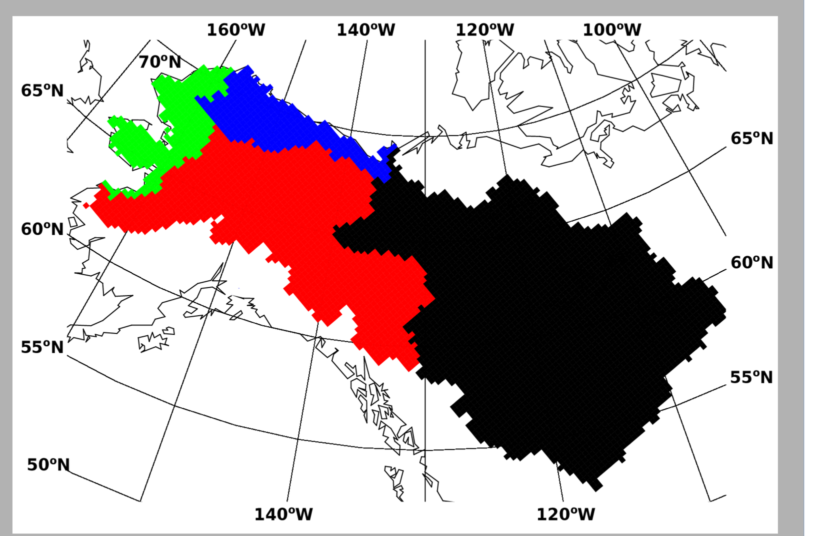
Abstract

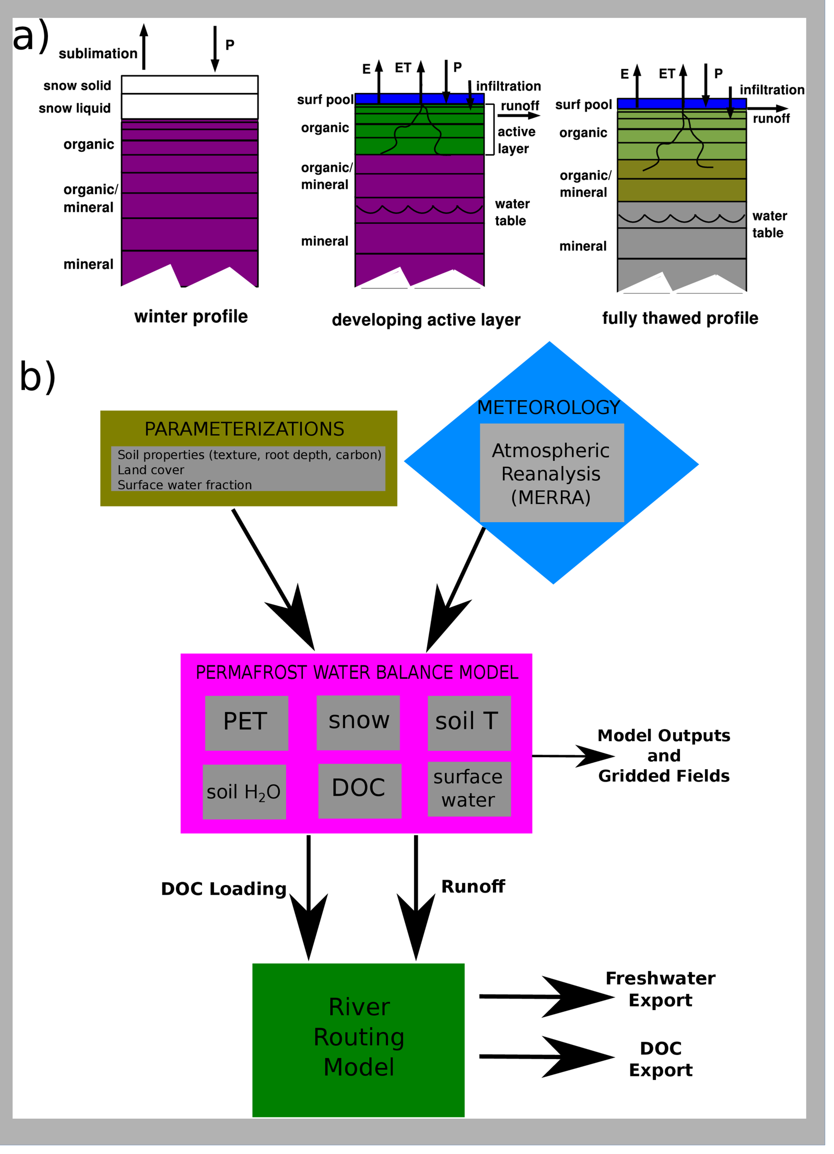
River systems play a prominent role in the lateral transfer of carbon and other constituents to world oceans, with Arctic rivers carrying relatively high concentrations. Studies at a wide-range of scales have documented how climate changes including hydrological cycle intensification, warming-induced permafrost thaw, active layer deepening, and changes in growing season length and productivity are impacting carbon mobilization and riverine DOC export. Influences on carbon mobilization include the amount and quality of soil organic matter, vegetation, topography, and climate. The overarching goal of this research is to advance understanding of the mobilization and transfer of riverine nutrients, the associated proportional contributions from surface and subsurface flows, and potential change under a warming climate. In this study process modeling is employed to simulate soil DOC production and associated loading to rivers across the western Arctic including and between the Yukon and Mackenzie rivers. Algorithms for DOC production and leaching are incorporated into the Permafrost Water Balance Model (PWBM), with soil DOC production rates based on the amount and decomposition of soil organic matter, soil temperature and moisture. Soil carbon content is parameterized from the Northern Circumpolar Soil Carbon Database with an exponential decay with depth across model soil layers. The simulations demonstrate variable DOC concentrations in runoff originating from surface flow and through the soil profile, which in part explain variations in DOC concentration observed in the region's rivers. Following calibration the model is able to capture much of the seasonal variation in DOC concentrations and spatial variability in DOC export from the Yukon, Mackenzie, and several North Slope rivers where measurements are available. The model simulations help to elucidate the influence of climate and watershed characteristics on terrestrial carbon dynamics, the proportion of carbon transported to the coast, and the fate of DOC within inland water networks and coastal zones..

Study Region and Model

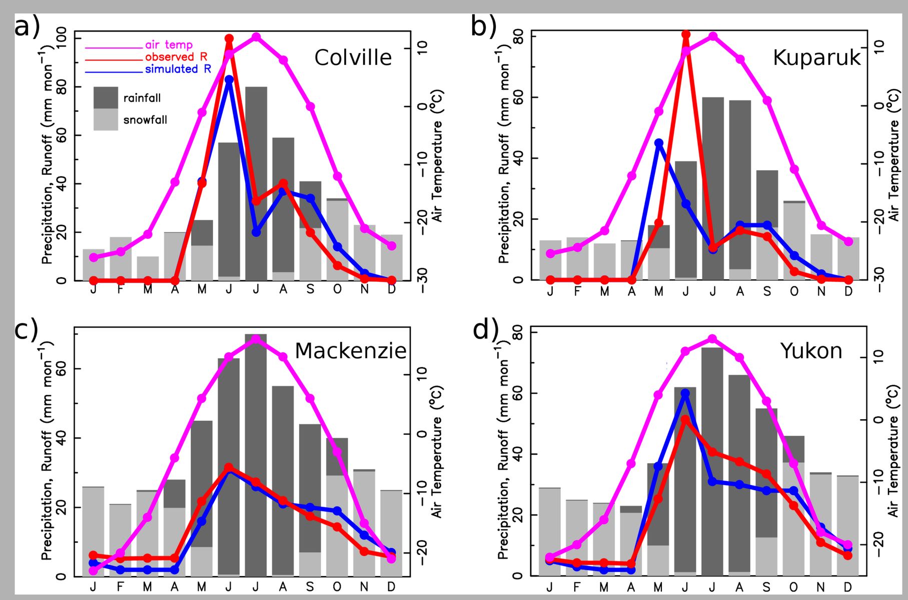
The spatial domain includes all land areas that drain river basins with outlets between (and including) the Yukon and Mackenzie Rivers. This region spans some 3,018,675 km2 and is resolved into 4804 grid cells.



(a) Schematic diagram of the vertical profiles for the Permafrost Water Balance Model (PWBM, Rawlins et al. 2013, 2019) illustrating characteristic water storage and flux elements for winter, late spring when active layer is developing, and a thawed profile consistent with summer in an area absent of permafrost. b) Flowchart showing model parameterizations, forcings, outputs, and submodels used to estimate DOC loading and export to coastal zones. No river routing modeling is employed in the present study.



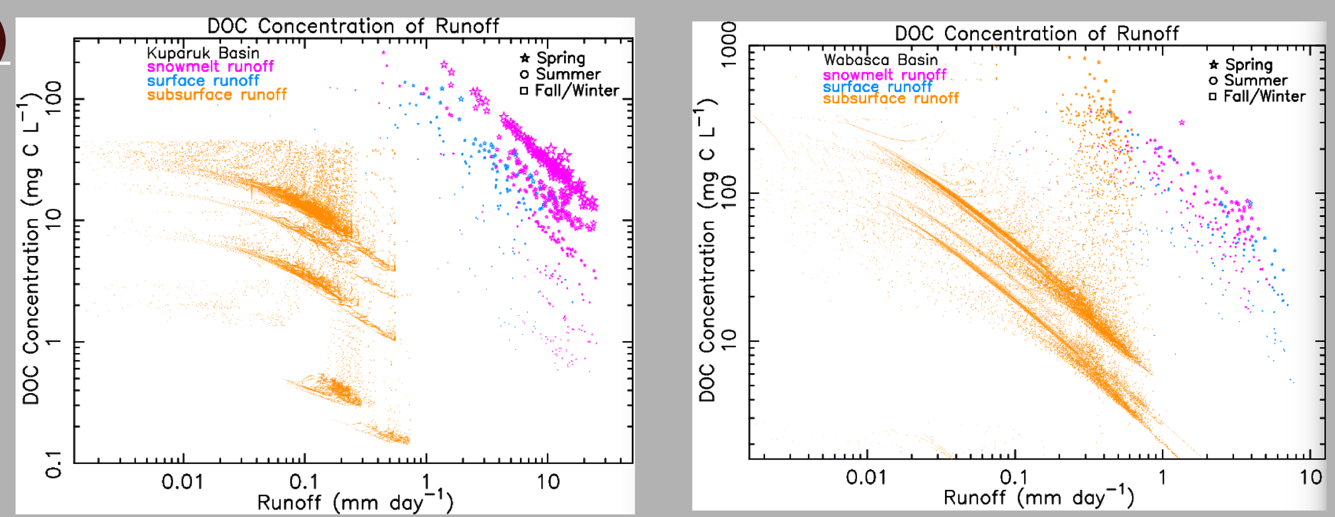
Model Validation - Runoff



Observed and simulated runoff and air temperature for four rivers in the region with the longest records; the Colville and Kuparuk in northern Alaska and the large Mackenzie and Yukon rivers. The magnitude of annual total runoff and seasonal cycle from high freshet runoff through recession and winter low flows are generally well captured. Mean percent error for annual runoff is −3.3,−11.3,−4.7, and +1.2%.

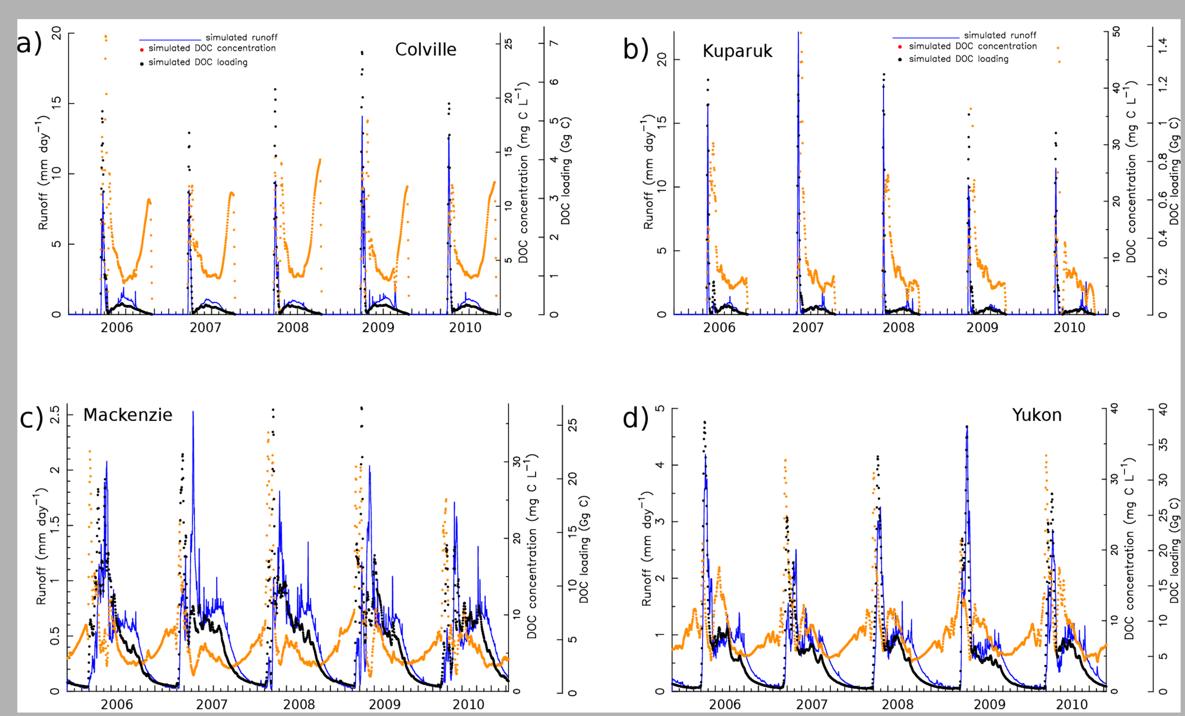
Model Validation - DOC

a)

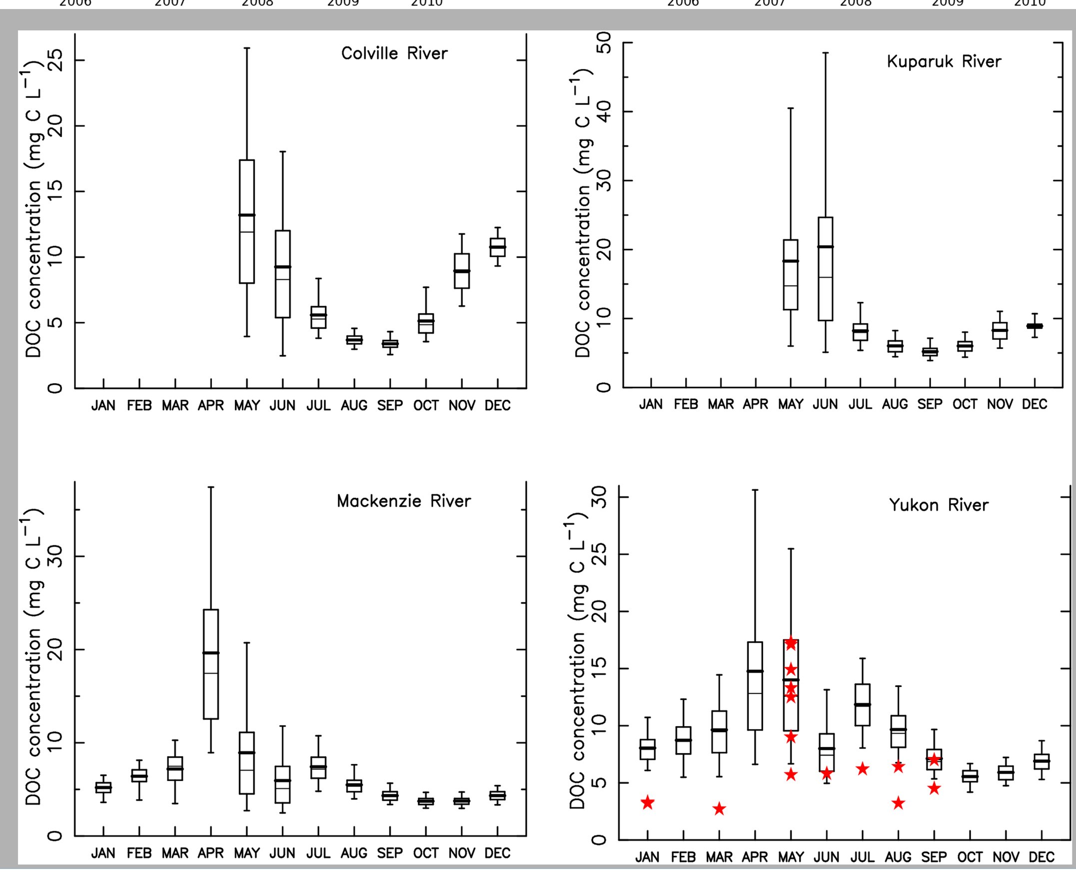


(a) Simulated leachate concentrations in the Kuparuk basin are highest during spring and emanate from surface snowmelt runoff. A dilution effect is noted in both surface and subsurface runoff. As with the Kuparuk an inverse relationship is shown between concentration and flow rate in subsurface runoff. (b) The highest concentrations occur near the time of maximum runoff for each of the four basins. (c) Monthly distributions show highest simulated concentrations during the spring freshet. For the Mackenzie the loaded leachate concentrations are often highest in late April, several weeks before peak discharge in early June.

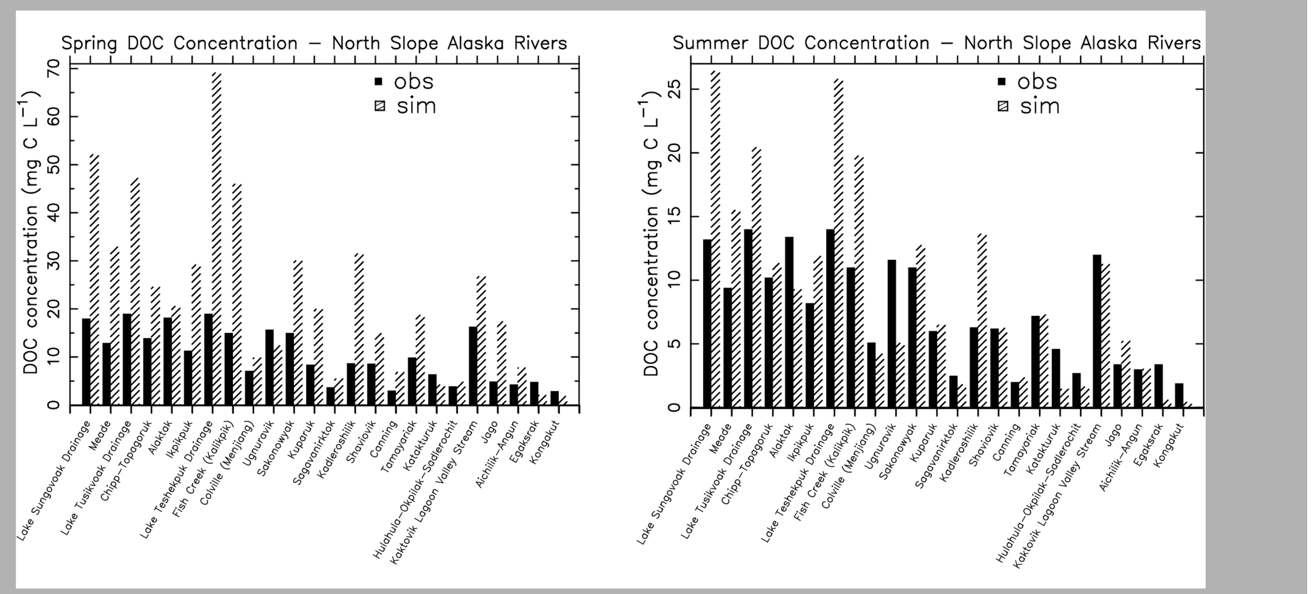
b)



c)



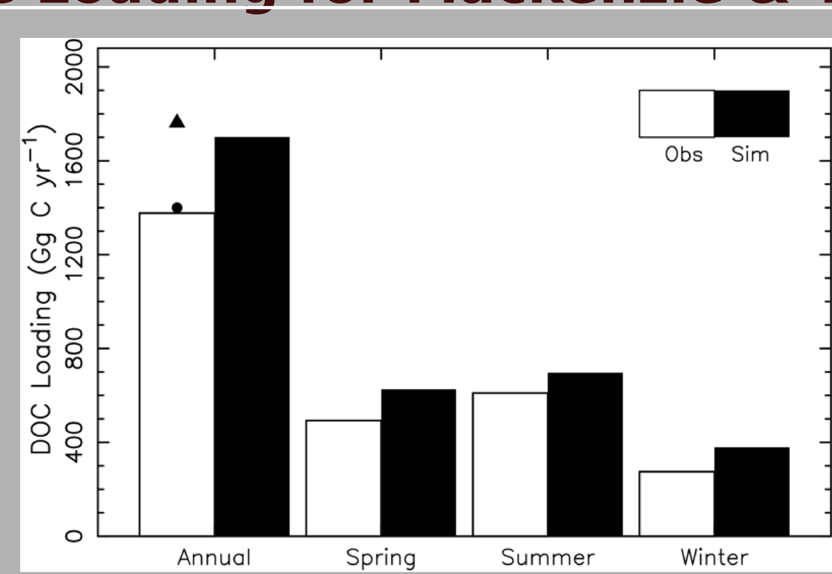
DOC Concentration of North Slope Rivers



Simulated leachate DOC concentrations in spring (May-June) and summer (July-September) for 24 North Slope rivers express an east-west gradient that is broadly consistent with independent estimates derived from river sampling (Connolly et al., 2018). The model overestimates concentrations for several rivers to the west, though leachate concentrations loaded to rivers are expected to be higher given losses in transit to the coast. The gradient is proportional to the amount of topographic relief across the river basin.

DOC Loading for Mackenzie & Yukon

a)



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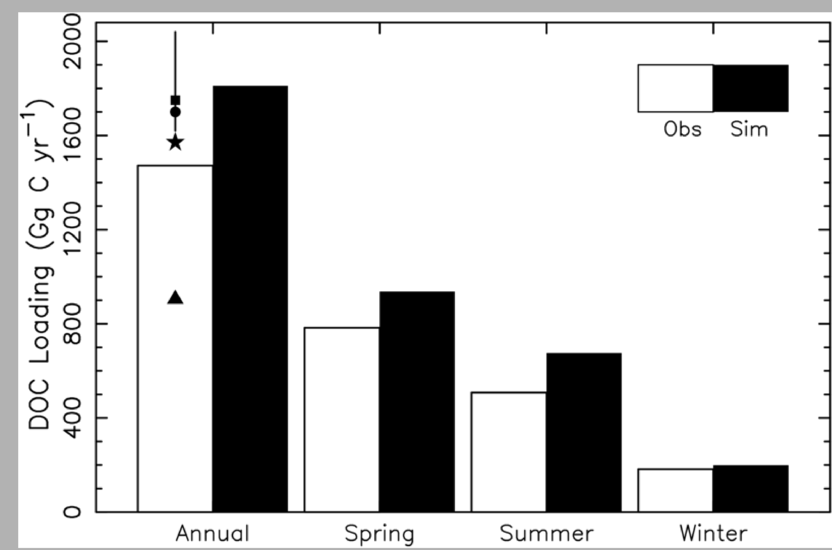

Seasonal climatologies for loading for the (a) Mackenzie and (b) Yukon agree well with export totals from river sampling reported in other studies. Simulated annual loading is within the range of the export totals. For the Mackenzie, simulated loading total is close to the estimate from TEM. Consistent with the export totals, the model simulates highest loadings in spring (May-June) and summer (July-October) for the Mackenzie and Yukon, respectively. Much lower simulated loadings in winter are consistent with export data from measured samples.

References

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